Gated Microchannel Plate Photomultipliers For Longitudinal Beam Diagnostics*

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Abstract. A gated microchannel plate photomultiplier can be used as an effective tool for measuring the longitudinal distribution of particles around most electron and high-energy proton rings. The broad available wavelength range, low noise, and high sensitivity allow using such a device for measuring the emitted synchrotron radiation and to extract the beam intensity. The fast gate rise time can be used to reject strong signals coming from filled RF buckets and avoid saturation of the photocathode so that it is possible to monitor, with a high degree of resolution, gaps in the machine fill and growth of parasitic bunches. The rugged characteristics of the device and its simplicity of use make it ideal for all those applications where more complex and expensive instrumentation is not absolutely necessary. We present the experimental results obtained at the Advanced Light Source and on the Tevatron using an Hamamatsu R5916U-50 series model.

Keywords: Synchrotron radiation, longitudinal diagnostics, photomultiplier, storage ring.
PACS: 41.85.Ew, 85.60.Ha

INTRODUCTION

Measurement of the emitted synchrotron radiation from storage rings is one of the primary means for beam diagnostics. Basically, all electron rings and the high-energy proton machines naturally generate photon fluxes that can be usefully utilized for measuring several beam parameters. Differently from the electromagnetic fields used by more classical diagnostic devices (i.e. BPM's, striplines, etc.), synchrotron emission at optical or quasi-optical wavelengths is strongly temporally correlated with the emitting particles and doesn't present those long tails typical of lower frequencies. Also, the optoelectronic circuitry used by the detection devices has response times that are much shorter than those of the standard microwave components.

In this paper, we present a measurement technique which makes use of a gated microchannel-plate photomultiplier (MCP-PMT). This technique was initially proposed for an abort gap monitor for the Large Hadron Collider [1] and has been successfully tested at the Advanced Light Source [2] and on the Tevatron [3].

In the following paragraphs we illustrate the features of such a device, pointing out its advantages over other methods; show the results obtained at the ALS and on the Tevatron; and compare the MCP-PMT characteristics with the specifications for

* Work supported by the U. S. Department of Energy under Contract No. DE-AC0-05CH11231.

several applications, such as measurements of bunch length, bunch intensity and phase transients, ghost bunches and fill gaps monitoring.

THE GATED MICROCHANNEL PLATE PHOTOMULTIPLIER

A gated MCP-PMT [4] features a gate between cathode and microchannel plate of a photomultiplier tube (Fig.1).

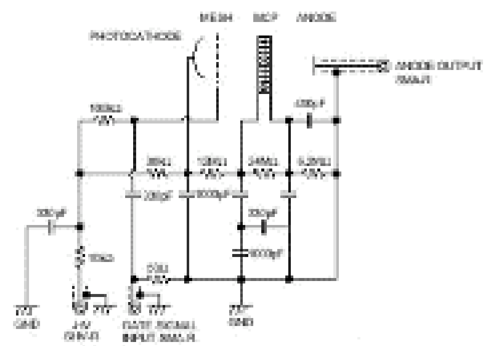

FIGURE 1. Equivalent circuit of the Hamamatsu gated MCP-PMT.

This allows for effectively gating the component response, which can then be used to sample the beam around the machine. Since the gate shuts off the MCP input, there is no accumulation of charges inside the tube when the gate is off. In this way it is possible to maintain a high sensitivity, even near very intense bunches, which can be "gated off" and would otherwise saturate the tube.

Typical gate rise time and minimum width are of the order of 1 and 5 ps respectively, with a maximum duty factor of 1%. A variety of photocathodes available can cover different wavelengths with quantum efficiencies up to 20%, as shown in Fig.2.

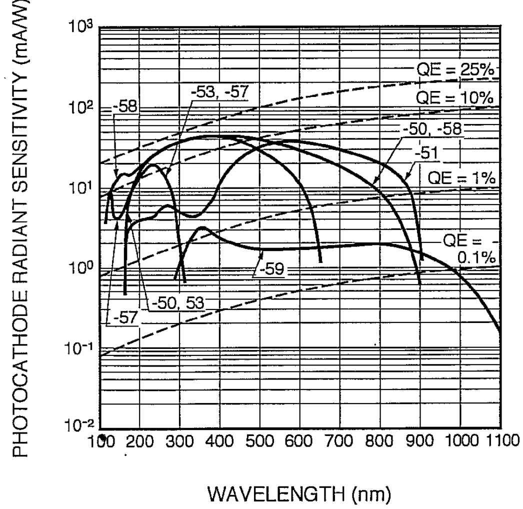

FIGURE 2. Spectral response of Hamamatsu photocathode

The tube typical gain is in excess of 10^5 and its dark current a few nA.

Figure 3 shows the Instrument Response Function (IRF), which is an approximation of the impulse response of the component. We see that there is a transit time spread effect of a little less than 100 ps and that the signal falls to less than 1% of its peak in a few hundreds of ps.

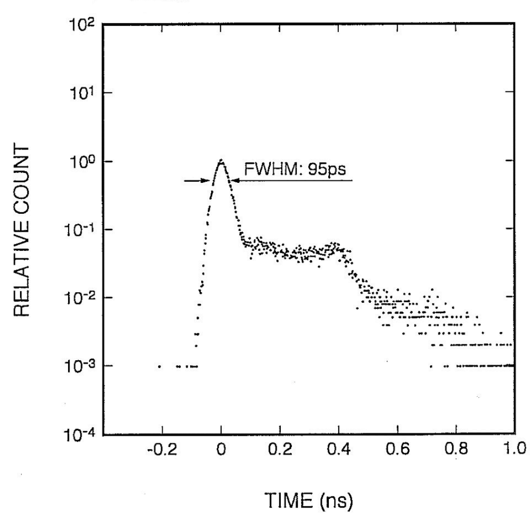

FIGURE 3. Instrument Response Function

MEASUREMENTS AT THE ALS AND AT THE TEVATRON

We have made extensive use of a Hamamatsu R5916U-50 gated MCP-PMT both at the Advanced Light Source and at the Tevatron. The use on two machines so different from each other (Tab.1) gives an idea of the variety of possible applications and of the device flexibility.

TABLE 1. Machine Parameters.

	ALS	Tevatron
Energy (GeV)	1.9	1000
Revolution Frequency (MHz)	1.52	0.048
Bunch Length (ps)	20	1400
Bunch Charge	$6\ 10^{9}\ e^{-}$	$3\ 10^{11}\ p^{+}$
RF Buckets Length (ns)	2	19

Measurements at the Advanced Light Source

At the ALS we performed our measurements on a dedicated diagnostic beamline (BL 3.1), which uses the synchrotron radiation out of one of the 1.3 T dipoles at visible light wavelengths.

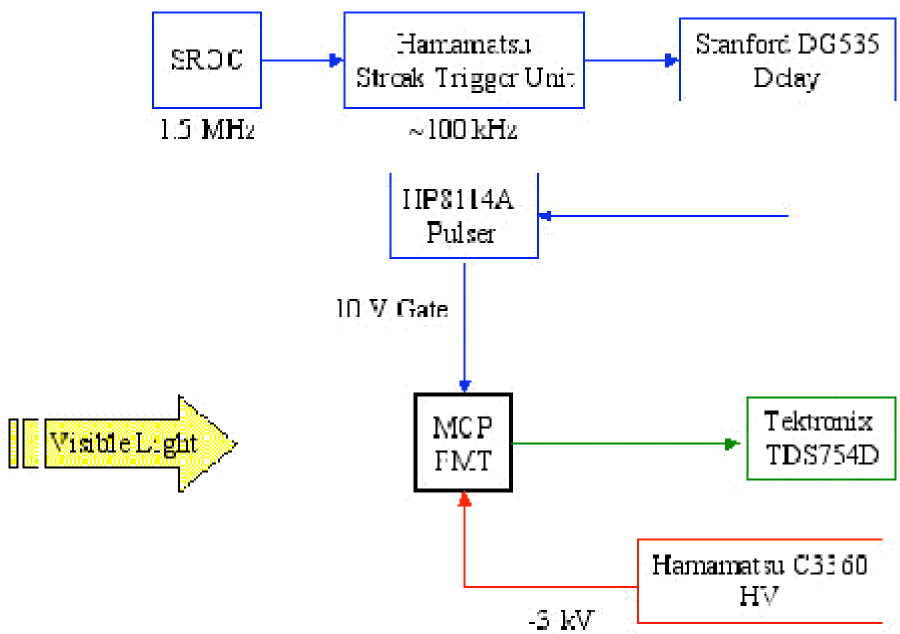

FIGURE 4. Block diagram of the experimental setup.

Figure 4 shows our simple setup: the 10 V gating pulse is synchronized to the orbit clock (SROC) and can be shifted using an external delay box, thus effectively mapping the circulating charges all around the ring. To stay within the 1% duty cycle, one can have a maximum gate width of about 6 ns (3 RF buckets), but if there is no need to take a measurement at every turn, one can slow the gate pulser repetition frequency and proportionally increase the observation window.

The ALS features a 100 ns gap in the bunch train and a special high-current bunch (referred to as *camshaft*) in the middle of the fill gap which, after a while, is followed by very low-current parasitic bunches due to diffusion of electrons from the camshaft into the next RF buckets (Fig.5).

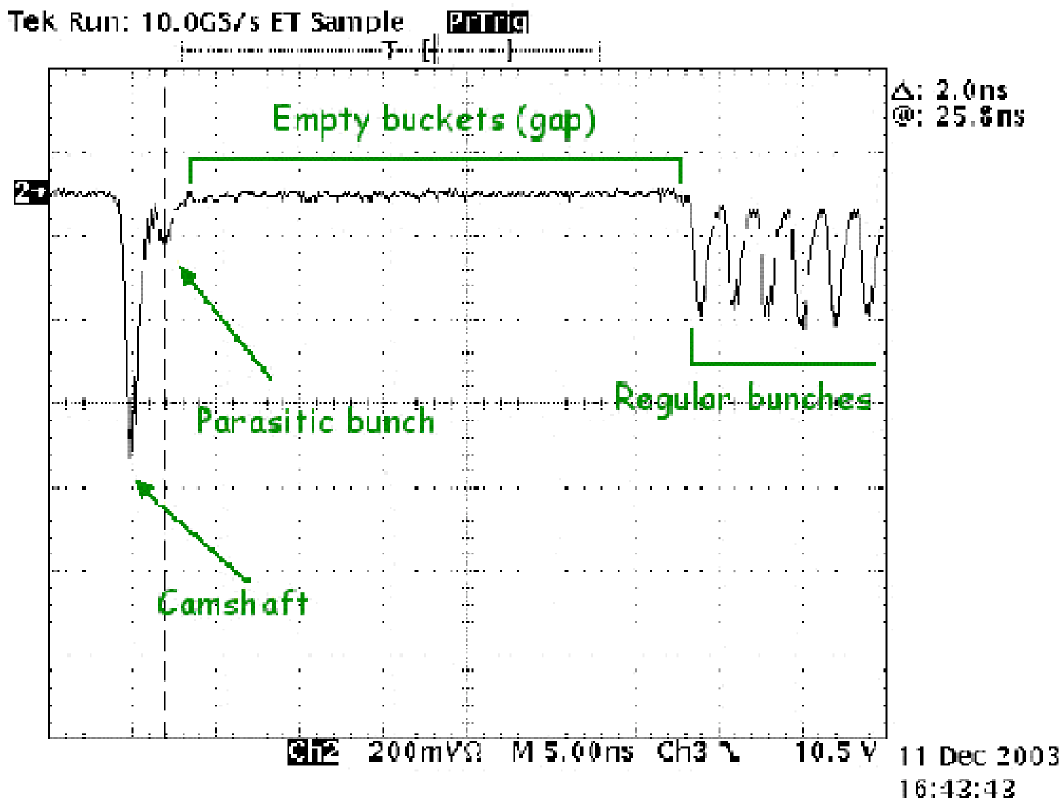

FIGURE 5. Image of the ALS camshaft, with parasitic bunch.

Figure 6 shows how the gating capabilities of the MCP-PMT (the gate rise time is less than the RF bucket separation) can be used to measure very low charge intensities, right next to much larger ones.

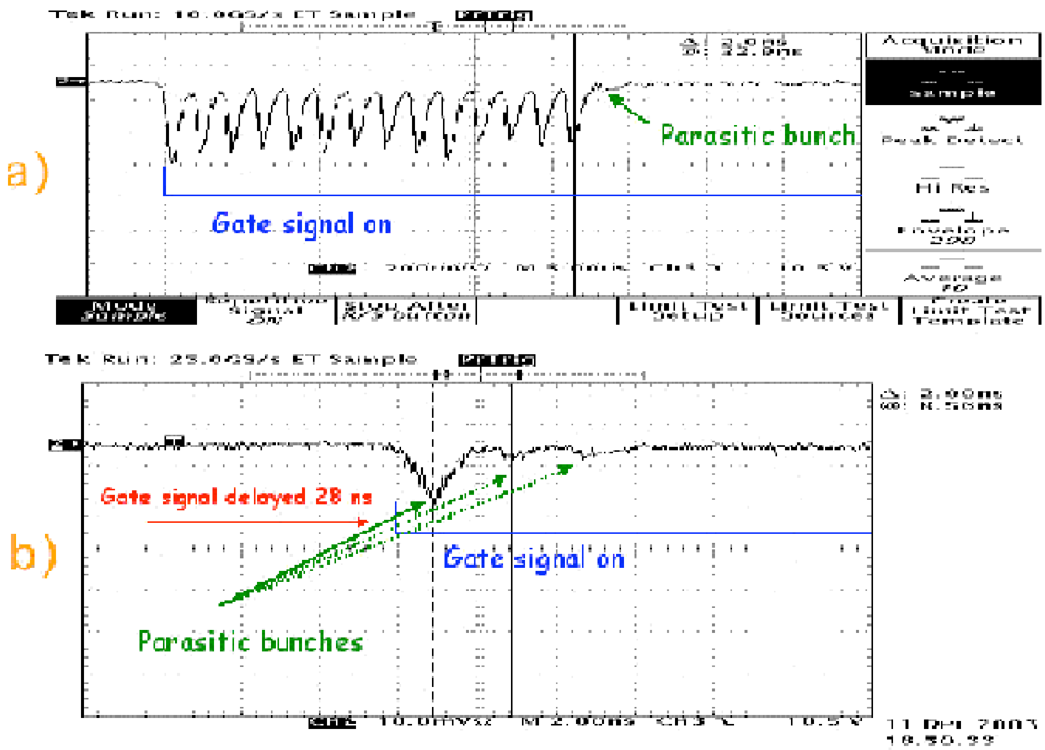

FIGURE 6. a) Last 14 bunches of the ALS train and adjacent gap. b) Filled RF buckets are gated out by shifting the gate signal. The vertical scale is enlarged to show trailing parasitic bunches.

Figures 5 and 6 were obtained without any form of signal integration. It would be possible, for instance, to integrate for a few tens of turns and extract quite precisely the position of the center of every bunch, with respect to the orbit clock. This would give a direct measurement of the synchronous phase variation along the train due to beam loading effects and the presence of a large gap.

Measurements at the Tevatron

The experimental activity at the Tevatron was mainly connected to the implementation of a monitor for residual charges in the abort gaps.

The Tevatron proton beam consists of 3 trains of 12 bunches each, separated by 2.6 μs-long abort gaps (139 RF buckets). Differently from the ALS, where the beam is strongly bunched, in a proton machine particles escaping the RF bucket can continue to circulate unbunched for several minutes. These are referred to as *DC beam*. The presence of beam in the abort gaps is highly undesirable because of possible damage to the detectors and SC magnets due to sprayed particles during kicker ramps. To avoid that, the ring is equipped with an electron lens (TEL) which is turned on during most of the abort gap to keep it free of particles.

The experimental setup is essentially analogous to the ALS, except that the MCP-PMT output is connected to a fast integrator and a VME digitizer. Due to the lower synchrotron radiation intensity in the visible range, data is collected and averaged for 1000 revolutions in order to obtain a better signal-to-noise ratio.

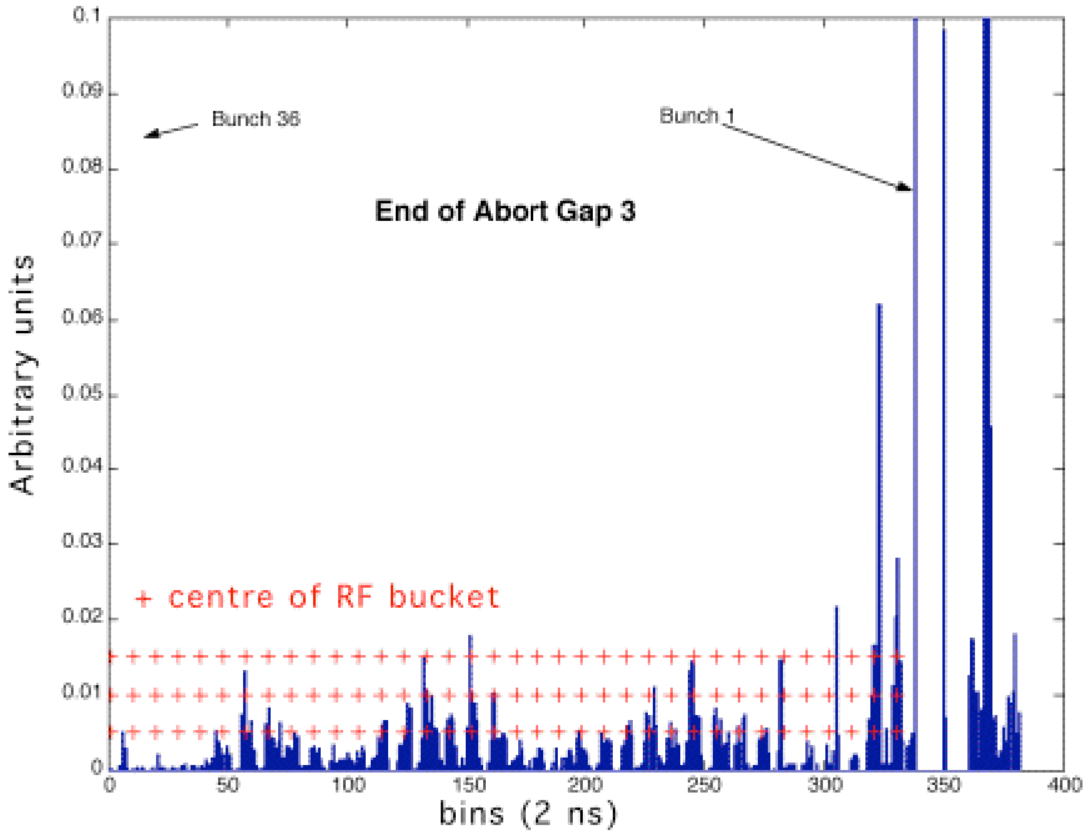

FIGURE 7. Final portion of the Tevatron abort gap and bunch #1.

Figure 7 shows a measurement of the final portion of one of the abort gaps. It can be noted that, although the TEL is switched off during this final part of the gap, only bunched beam survives.

Reducing the gate width to 19 ns and changing the delay appropriately, we monitored one third of the ring (one abort gap + one bunch train) with a resolution corresponding to a single RF bucket during a period of about forty minutes when the TEL was turned off.

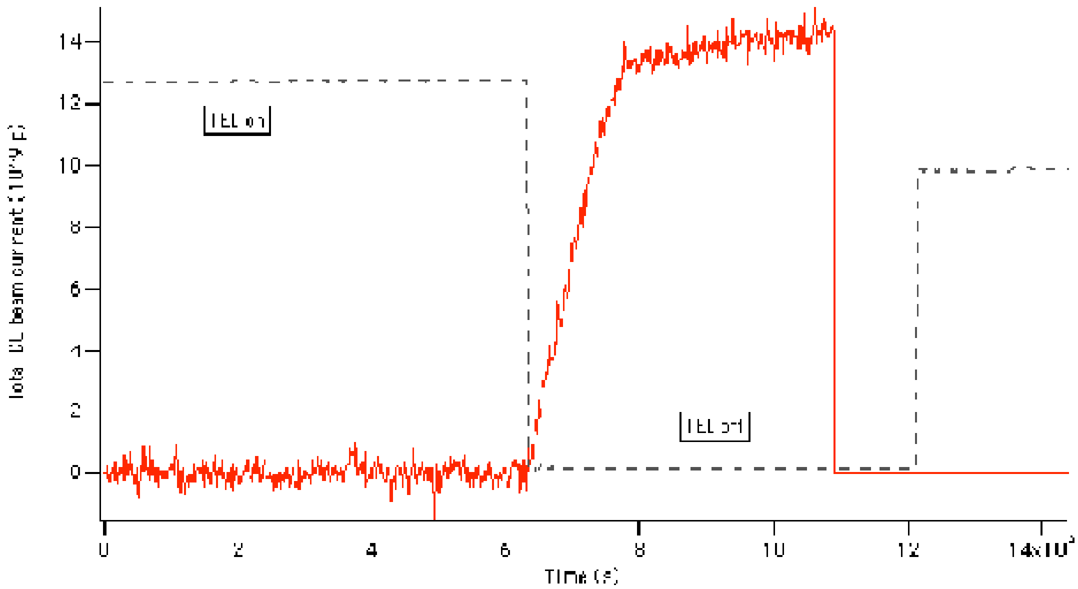

FIGURE 8. Total uncaptured beam intensity around the ring.

Figure 8 shows the progressive increase of DC current as the TEL is turned off, until the beam is dumped. All the particles that escaped the RF bucket and would have been ejected by the TEL are instead allowed to accumulate.

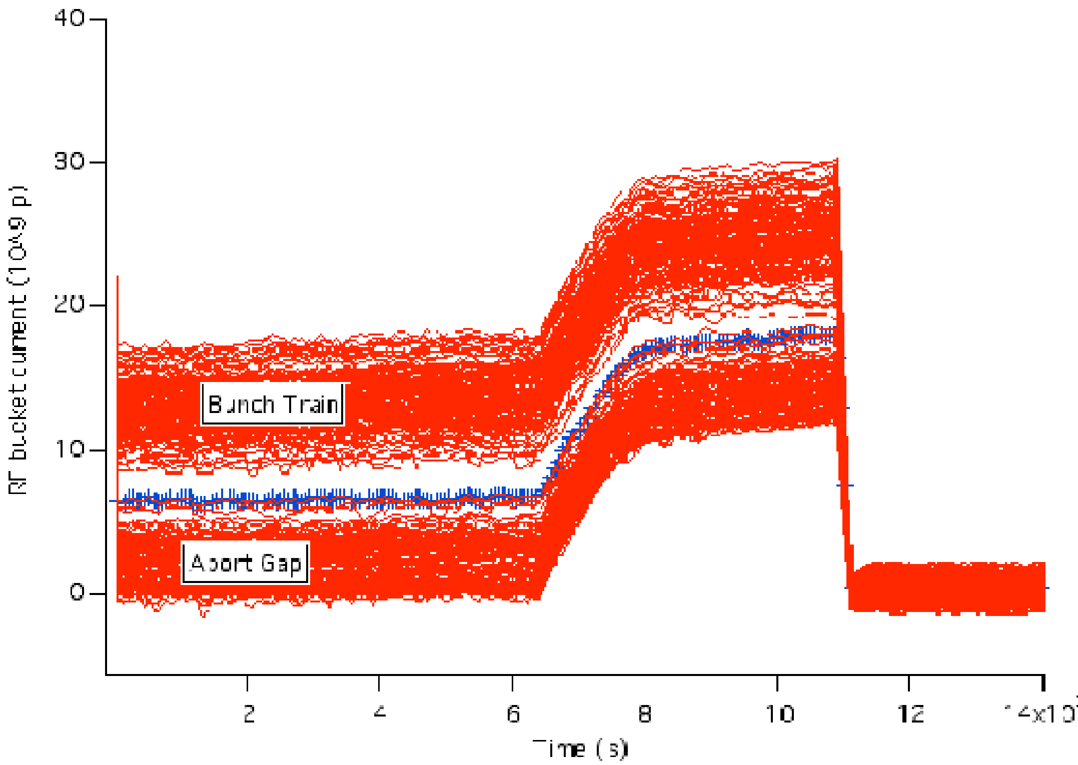

FIGURE 9. Beam intensity in individual RF buckets over one-third of the ring. “Bunch Train” denotes the nominally empty RF buckets in between filled bunches.

The traces in Fig. 9 show the measurement result when the gate width and timing coincided with all the RF buckets over one-third of the ring. The measurement relative to the 12 filled bunches has been discarded. There seems to be no growth variation between buckets in coincidence with the increase in total DC beam, pointing out that the beam diffuses uniformly around the ring, as opposed to the ALS case (Fig.6b) where, because of a much higher recapture probability, lost electrons diffuse from one RF bucket to the next.

The data in Fig. 9 also shows a difference between the current in the abort gap buckets and that in the train region, as the latter has substantially higher current when the TEL is on. This current corresponds to protons that, during the injection process, are captured by the nominally empty RF buckets in between the filled bunches.

CONCLUSIONS

In this paper we have shown how a gated microchannel plate photomultiplier can be used for a variety of measurements utilizing the synchrotron light emitted by both electron and high-energy proton rings.

With an MCP-PMT and relatively simple electronics it is possible to obtain a valid diagnostic instrument that allows measurement of the distribution of particles around a storage ring with high sensitivity.

In our opinion, an MCP-PMT-based instrument is a valid substitute for a streak camera in all those applications that don't require resolutions under 100 ps, for a fraction of the cost.

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